Introduction

The Big Picture

We do not just drink water; we are water. Water constitutes 50 to 90 percent of the weight of all living organisms. It is one of the most abundant and important substances on the Earth. Water sustains plant and animal life, plays a key role in the formation of weather, helps to shape the surface of the planet through erosion and other processes, and covers roughly 70% of the Earth's surface.

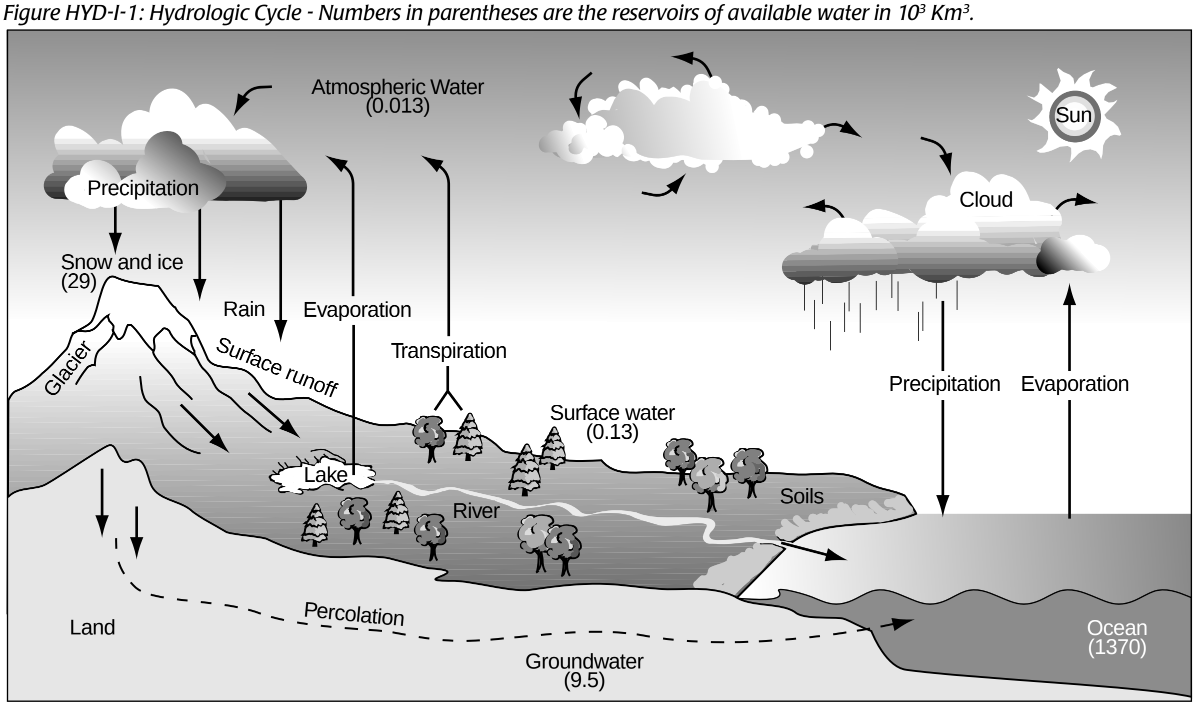
Water continually circulates between the Earth's surface and its atmosphere in what is called the hydrologic cycle. The hydrologic or water cycle, is one of the basic processes in nature. Responding to heat from the sun and other influences, water from the oceans, rivers, lakes, soils and vegetation evaporates into the air and becomes water vapor. The water vapor rises into the atmosphere, cools, and turns into liquid water or ice, forming clouds. When the water droplets or ice crystals get large enough, they fall back to the surface as rain or snow. Once on the ground, water does one of three things; some of it filters into the soil and is either absorbed by plants or percolates downward to groundwater reservoirs. Some runs off into streams and rivers and eventually into the oceans. Some evaporates.

The water in a lake, the snow on a mountain, the humid air or the drop of morning dew are all part of the same system. The total annual water loss from the surface of the planet equals the Earth's total annual precipitation. Changing any part of the system, such as the amount of vegetation in a region or land uses, affects the rest of the system.

Despite its abundance, we cannot use most of Earth's water. If we represent the Earth's water as 100 liters, 97 of them would be seawater. Most of the remaining three would be ice. Only about 3 mL out of the whole 100 liters would be water that we can consume; that water is pumped from the ground or taken from fresh water rivers and lakes.

Water participates in many important chemical reactions, and most substances are soluble in water. Due to its effectiveness as a solvent, truly

Figure HYD-I-1: Hydrologic Cycle - Numbers in parentheses are the reservoirs of available water in 10^3 Km^3.



After Mackenzie and Mackenzie 1995, and Graedel and Crutzen, 1993 pure water rarely occurs in nature. Water carries many natural and human-introduced impurities as it travels through the hydrologic cycle. These impurities give each water its distinctive chemical makeup, or *quality*. Rain and snow capture small dust particles or *aerosols* from the air, and sunlight causes emissions from the burning of gasoline and other fossil fuels to react with water to form sulfuric and nitric acids. These pollutants return to Earth as *acid rain or snow*. The acids in the water slowly dissolve rocks, placing *dissolved* solids in water. Small but visible pieces of the rocks and soils also enter the water, resulting in *suspended* solids and making some waters turbid. When water percolates into the ground, it is in very close contact with rocks and more minerals dissolve into the water. These impurities dissolved or suspended in water determine its quality.

In this investigation, students will measure the following key indicators of water quality.

Transparency

Light, essential for growth of green plants, travels further in clear water than in either *turbid* water that contains suspended solids or colored water. Two methods that are commonly used to measure the transparency, or degree to which light penetrates into water, are the Secchi disk and turbidity tube. Secchi disk transparency was first measured in 1865 by Father Pietro Angelo Secchi, scientific advisor to the Pope. This simple and widely used measurement is the depth at which a 20-cm black and white disk lowered into water just disappears from view, and reappears again when raised. An alternate measure of transparency is obtained by pouring water into a tube with a pattern similar to that of a Secchi disk on the bottom and noting the depth of water in the tube when the pattern just disappears from view. The Secchi disk is used in deeper, still waters; the turbidity tube can be used with either still or flowing waters and can be used to measure shallow water sites or the surface layer of deep water sites.

Sunlight provides the energy for photosynthesis, the process by which plants grow by taking up carbon, nitrogen, phosphorus and other nutrients, and give off oxygen. Thus penetration of sunlight into a water body determines the depth to which algae and other plants can grow, and the relative amount of growth. Transparency decreases as color, suspended sediments, or algal abundance increases. Water is colored by the presence and action of some bacteria, phytoplankton, and other organisms, by chemicals leached from soil, and by decaying plant matter. Therefore, the amount of plant nutrients coming into a body of water from sources such as sewage treatment plants, septic tanks, fertilizer run-off, and wind and water born plant debris affects transparency. Suspended sediments often come from sources such as agriculture, construction, storm runoff and resuspension of bottom sediments.

Most natural waters have transparency ranging from 1 meter to a few meters. A low value, under 1 meter, would be expected in a highly productive body of water. A low value can be due as well to a high concentration of suspended solids. Extremely clear, unproductive lakes or coastal waters can have transparency up to 30 - 40 m as can the areas around coral reefs.

Water Temperature

Water temperature is largely determined by the amount of solar energy absorbed by the water and the surrounding soil and air. More solar heating leads to higher water temperatures. Water that has been used in manufacturing and discharged into a water body may also increase water temperature. Water evaporating from the surface can lower the temperature of the water but only for a very thin layer at the surface. We need to measure water temperature to understand the patterns of change over the year because the temperature of a water body strongly influences the amount and diversity of its aquatic life. Lakes that are relatively cold and have little plant life in winter bloom in the spring and summer when water temperatures rise and the nutrient-rich bottom waters mix with the upper waters. One also finds periods of mixing in the fall. Because of this mixing and the warmer water temperatures, the spring overturn is followed by a period of rapid growth of microscopic aquatic plants and animals. Many fish and other aquatic animals also spawn at this time of year when the temperatures rise and food is abundant. Shallow lakes are an exception to this cycle, as they mix throughout the year. One concern is that warm water can be fatal for sensitive species, such as trout or salmon, which require cold, oxygen-rich conditions.

Dissolved Oxygen

Water is a molecule made of two hydrogen atoms and one oxygen atom - hence, H_2O. However, mixed in with the water molecules of any body of water are molecules of oxygen gas (O_2) that have dissolved in the water. Dissolved oxygen is a natural impurity in water. Aquatic animals, such as fish and the zooplankton they feed on, do not breathe the oxygen in water molecules; they breathe the oxygen molecules dissolved throughout the water. Without sufficient levels of dissolved oxygen in the water, aquatic life suffocates. Dissolved oxygen levels below 3 mg/L are stressful to most aquatic organisms.

In the atmosphere, roughly one out of every five molecules is oxygen; in water, about one to ten molecules in every million molecules are oxygen. Vigorous mixing of air and water, such as in turbulent streams, increases the amount of oxygen dissolved in water. So does photosynthesis by aquatic plants. Oxygen is consumed by fish, zooplankton, and the bacteria that decompose organic materials. Organic materials such as dead plant and animal matter enter streams naturally in water draining from forests and grass or crop lands. Another source of organic matter is outfalls from sewage treatment plants. Whatever the source, we tend to find low dissolved oxygen levels, well under half the saturated value, in slow-moving streams near sources of organic matter. In addition, warm water holds less oxygen than cold water, so critical periods for fish and zooplankton tend to occur in summer. For example, at 25° C, dissolved oxygen solubility is 8.3 mg/L, whereas at 4° C the solubility is 13.1 mg/L.

pH

pH is a measure of the acid content of water. The pH of a water influences most of its chemical processes. Pure water with no impurities (and not in contact with air) has a pH of 7. Water with impurities will have a pH of 7 when its acid and base content are exactly equal and balance each other out. At pH values below 7 we have excess acid, and at pH levels above 7 we have excess base in the water.

The pH scale is different from the concentration scale we use for other impurities. It is logarithmic, which means that a one-unit change in pH represents a factor of ten change in the acid content of the water. Thus water with a pH of 3 has ten times the acid content of water with a pH of 4, which in turn has ten times the acid content of water with a pH of 5.

Natural, unpolluted rain has a pH between 5 and 6, so even rain water from the least polluted place on Earth has some natural acidity. This natural acidity is the result of carbon dioxide from the air dissolving in the rain drops. Distilled water which is in equilibrium with the air will have this same pH. The most acidic rain has a pH of about 4, though urban fogs with pH of less than 2 have been measured. Most lakes and streams have pH's in the range of 6.5 to 8.5. One can find waters that are naturally more acidic in areas with certain types of minerals in the soil, (e.g., sulfides). Mining activity can also release acid-causing minerals to a stream. Naturally basic waters are found typically in areas where the soil contains minerals such as calcite or limestone.

The pH of a water body has a strong influence on what can live in it. Salamanders, frogs and other amphibian life are particularly sensitive to low pH. Most insects, amphibians, and fish are absent in water bodies with pH below 4.

Electrical Conductivity

Pure water is a poor conductor of electricity. It is the impurities in water, such as dissolved salts, that enable water to conduct electricity. Since we lack the time or money to analyze water for each substance, we have found a good indicator of the total level of impurities in fresh water to be its electrical conductivity - how well a water passes electrical current. The more impurities in water, the greater its electrical conductivity.

For most agricultural and municipal uses, we want water that has a total dissolved solids content well below 1000-1200 parts impurity per million parts water by weight (ppm), or an electrical conductivity (ability to pass electrical current) below about 1500-1800 microSiemens/cm (Note that 1 ppm = 1mg/L). Above these levels, one can expect damage to sensitive crops. For household use, we prefer water with a total dissolved-solids content below about 500 ppm, or below a conductivity of about 750 microSiemens/cm. The residues left on "clean" dishes just out of the automatic dishwasher are a product of dissolved solids in water. Manufacturing, especially of electronics, requires impurity-free water. Pure, alpine snow from remote areas has a conductivity of about 5-30 microSiemens/cm.

Salinity

The sea is salty; it has a much higher dissolved solids content than do fresh waters. Salinity is a measure of that saltiness and is expressed in parts impurity per thousand parts water. The average salinity of the Earth's oceans is 35 parts per thousand (35 ppt). Sodium and chloride, the components of common table salt (NaCl), contribute the most to the salinity. Since the proportion of chloride in seawater changes little from place to place we can also measure the chloride content, referred to as chlorinity, to estimate the total salinity. In bays and estuaries we can find a wide range of salinity values, since these are the regions where freshwaters and seawater mix. The salinity of these *brackish* waters is between that of freshwater, which averages 0.5 ppt, and seawater.

Every continent on Earth also has inland lakes that are saline. Some of the more prominent examples are the Caspian Sea in Central Asia, the Great Salt Lake in North America, and several lakes in the Great Rift Valley of East Africa. Some of these are even more saline than seawater. Waters acquire salinity because rivers carry salts that originated from the weathering or dissolving of continental rocks. When water evaporates the salts stay behind, resulting in a buildup of dissolved material. At some point the water becomes *saturated* with solids, they precipitate out as solids, and they settle out of the water. Whereas the ocean's salinity changes slowly, over many millennia, the salinity of inland waters can change more quickly when rainfall or snowmelt patterns change.

The salt content of a water body is one of the main factors determining what organisms will be found there. Thus fresh waters and saline waters are inhabited by quite different organisms. Plants and animals that live in or use freshwater (below 1 ppt) generally have a salt content inside their cells that is greater than the water they inhabit or use. They tend to give off salts as waste products. Saltwater plants and animals have a salt content equal to or less than the salinity of the surrounding water, and thus have different mechanisms for maintaining their salt balance. In brackish waters (salinity values of 1 - 10 ppt) we find plants and animals that can tolerate changes in salinity.

Alkalinity

Alkalinity is the measure of a water's resistance to the lowering of pH when acids are added to the water. Acid additions generally come from rain or snow, though soil sources are also important in some areas. Alkalinity is generated as water dissolves rocks containing calcium carbonate such as calcite and limestone. When a lake or stream has too little alkalinity, typically below about 100 mg/L, a large influx of acids from a big rainfall or rapid snowmelt event could (at least temporarily) consume all of the alkalinity and thus drop the pH of the water to levels harmful for amphibians, fish or zooplankton. We find lakes and streams in areas with little soil, such as in mountainous areas, are often low in alkalinity. These water bodies can be particularly sensitive in the spring during periods of rapid snowmelt. Because pollutants tend to wash out of a snowpack during the first part of snowmelt, we often encounter a higher influx of acidic pollutants in spring, which is also a critical time for the growth of aquatic life.

Nitrate

Plants in both fresh and saline waters require three major nutrients for growth: carbon, nitrogen and phosphorus. In fact, most plants tend to use these three nutrients in the same proportion, and cannot grow if one is in short supply. Carbon is relatively abundant in the air as carbon dioxide which dissolves in water, so a lack of either nitrogen or phosphorus generally limits the growth of aquatic plants. In some cases trace nutrients such as iron can also be limiting, as can sunlight. Nitrogen exists in water bodies in numerous forms: dissolved molecular nitrogen (N_2), organic compounds, ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-). Of these, nitrate is usually the most important. Nitrite is usually only present in suboxic waters (low dissolved oxygen levels). The nitrate form of nitrogen found in natural waters comes naturally from the atmosphere in rain, snow, fog or dry deposition, or from the decay of organic material in soil and sediments. It can also come from agricultural runoff; farmers add nitrogen fertilizer to crops, some of which drains out of the soil when it rains.

When an excess amount of a limiting nutrient such as nitrogen is added to a lake or stream the water becomes *enriched* and further growth of algae and other plants ensues. We call this process of enriching the water *eutrophication*. The resulting excess plant growth can cause taste and odor problems in lakes used for drinking water, can cause nuisance problems for users of the water body, or can adversely affect fish and other aquatic animals. Concerns about excess nitrogen or phosphorus in lakes and coastal waters are often associated with sewage discharges. Concentrations of nitrate should always be expressed as elemental nitrogen. Thus nitrate is expressed as nitrate nitrogen (NO_3–N) in milligrams per liter (that is, 14 g of nitrogen per mole of NO_3^-) and never as NO_3 (that is 62 g per mole NO_3^-). Most natural waters have nitrate levels under 1 mg/L nitrate nitrogen, but concentrations up to 10 mg/L nitrate nitrogen are found in some areas.

The Importance of Measurements

What is the condition of the Earth's many surface waters - the streams, rivers, lakes, and coastal waters? How do these conditions vary over the year? Are these conditions changing from year to year? Through the GLOBE *Hydrology Investigation*, your students, together with students at other GLOBE schools, address these questions by continuous, widespread monitoring of natural waters. Our knowledge of national and global trends in water quality is based on sampling at a very few representative sites. This sampling has generally been done only a few times. For example, our information on many lakes is based on sampling done only once or twice more than ten years ago. Before we can assess changes, we need reliable information on current conditions. When changes are already underway, comparison of affected and unaffected areas can help us understand what is happening.

Measures of dissolved oxygen and pH directly indicate how hospitable a body of water is to aquatic life. Again, it is interesting to both follow the annual cycle of dissolved oxygen, alkalinity and pH, and to make comparisons between different water bodies. We can ask such questions as: are dissolved oxygen levels always at the maximum allowed by the temperature of the water, or are they depressed during part of the year? If they are low, we want to know the cause. We can see if pH becomes depressed right after a rain or when there is a lot of snowmelt running off into the lake or stream. If we do find a depression in pH, we would expect that this water had a low level of alkalinity. In fact, we should expect that waters with a low alkalinity would have a depression in pH following rainfall or snowmelt. But we must make the measurement to confirm whether or not that really happens.

Students should make this suite of GLOBE measurements with at least two societal goals in mind. First, we want to develop a better understanding of our local land and water resources. This knowledge can help us make more intelligent decisions about how we use, manage and enjoy the resources. Second, we want to assess the extent to which human activities are affecting the quality of our water and thus affecting how we will be able to use it in the future. In most countries current measurement programs cover only a few water bodies at a few times during the year. We hope the measurements you make in the GLOBE program will help fill this gap and improve our understanding of the health of Earth's natural waters.

Preparing for the Field

Overview

Students will take samples of water from a selected body of water, process the samples to determine their composition, and analyze the data to come to better understand the quality of water and its impact on their environment.

Table HYD-I-1 lists the recommended protocols for the three levels of GLOBE. Teachers should use their own judgment as to which protocols are consistent with their students' abilities. Please note that the more advanced protocols involve special safety considerations.

Table HYD-I-1: Hydrology Measurement Levels

Level	Measurements
Beginning	transparency temperature pH (paper) conductivity or salinity
Intermediate/ Advanced	transparency temperature dissolved oxygen pH (pen or meter) conductivity or salinity alkalinity nitrate

Measurement Schedule

Measurements must be made one day per week, at the same time of day and on the same day of the week. Weekly measurements are particularly important during those times of the year when hydrology sites are undergoing rapid change. Samples can be collected for all protocols at each site visit.

Site Selection (in order of preference)

1. Stream or river
2. Lake, reservoir, bay or ocean
3. Pond
4. An irrigation ditch or other water body if one of the above is not accessible or available within your GLOBE Study Site.

Student Groups

Measurements should be taken by groups of 2-3 students. Tasks within a group include collecting samples, processing samples, and recording data. It is very useful to have multiple groups testing for each parameter (for example, two groups measure dissolved oxygen). This allows more students to get involved and builds in some quality control. Groups of students conducting the same test should look at each other's results to determine if the data are similar. If there are different results for the same sample, students should check the procedures and redo the test to determine what caused the difference. Data quality control should be an important part of the science and the learning experience.

Overview of Educational Activities

When the protocols for conducting each measurement are combined with the *Learning Activities*, a comprehensive program for understanding the chemistry of water bodies is established. There may be a temptation to have students merely take measurements and enter the data on the GLOBE data pages. However, gaining knowledge about science content, processes, and critical thinking skills are our educational goals. The *Learning Activities* will assist you in providing the context for the *Protocols*.

Student Learning Goals

This investigation develops students' understanding of the importance, unique properties and content of water. Through applications of water analyses, students come to understand water chemistry and how it is important in understanding the health of aquatic environments.

Upon completing all of the activities in this investigation, students should know and understand the following concepts and skills.

Concepts

- Water chemistry is an important aspect of habitat requirements
- Temperature can affect other water chemistry factors
- Water chemistry affects species diversity
- Instruments can enhance what your senses tell you about what is in water
- Data are used to pose and answer questions
- Graphs and maps are valuable tools for visualizing data
- Accuracy and precision are important when taking measurements
- The soil stores water, and its water content is related to the growth of vegetation
- Where rainfall goes depends on your site characteristics
- Higher temperatures and longer periods of sunshine increase evapotranspiration
- Water flows can change over time
- Water balance can be modeled using temperature, precipitation, and latitude data

Skills

- *Making* observations
- *Applying* field sampling techniques
- *Calibrating* scientific equipment
- *Following* directions in methods and test kits
- *Recording* and *reporting* data accurately
- *Reading* a scale
- *Communicating* orally
- *Communicating* in writing
- *Asking* Questions
- *Forming* and *testing* hypotheses
- *Designing* experiments, tools, and models
- *Using* water quality measurement equipment
- *Using* tools to enhance the senses
- *Creating* and *reading* graphs
- *Calculating* averages
- *Making* comparisons over space and time
- *Analyzing* data for trends and differences
- *Using* the GLOBE database

Student Assessment

Individual assessment of students' roles in this project and peer grading can be used, and the total study incorporated in students' portfolios. GLOBE Science Notebooks can be regularly assessed to chart the students' progress in understanding key science concepts, processes, and skills. They also can be the foundation for the development and assessment of communications skills, both written and oral. Reports and presentations should be designed using the material in the GLOBE Science Notebooks.

In addition to entering the data into the GLOBE Student Data Server, at levels where it is educationally appropriate, students should analyze their data and write reports. Have students write about the parameters they tested and compile all the individual reports into a complete study of the site. Submit the study to local and state agencies that govern water and water quality.

References

T.E. Graedel and P.J. Crutzen (1993) *Atmospheric Change: An Earth System Perspective*. W.H. Freeman and Company, New York

F.T. Mackenzie and J.A. Mackenzie (1995) *Our Changing Planet: An Introduction to Earth System Science and Global Environmental Change. Prentice* Hall, New Jersey.